Bidirectional Power Flow Control in AC/DC Hybrid System under AC and DC Fault Conditions

Wai Wai Hnin
Department of Electricacl Power Engineering
Yangon Technological University, Yangon ,Myanmar
waihninep@gmail.com

Zarchi linn
Department of Electrical Power Engineering
Yangon Technological University, Yangon, Myanmar
zarchilinn@ytu.edu.mm

Soe Win
Department of Electrical Power Engineering
Yangon Technological University, Yangon, Myanmar
soewin.ep@ytu.edu.mm

***Abstract*—This paper presents a hybrid AC-DC microgrid to reduce the process of multiple conversion in an individual AC microgrid or DC microgrid. The proposed hybrid microgrid composes of both AC microgrid and DC microgrid connected together by bidirectional interlink converter (BIC). Utility grid, 150kVA diesel generator (DG) and 100kW AC load are connected in AC microgrid. DC microgrid is composed of 100 kW photovoltaic array (PV), 20kW battery energy storage system (BESS) and 20kW DC load. The droop control technique is applied to control the system for power sharing within the sources in AC/DC hybrid microgrid in proportion to the power rating. When the faults occur at AC bus, protection signal applied to breaker for isolating the healthy and faulted system. When DC fault occurs at DC bus, DC breaker isolate the AC and DC bus. The system performance for power flow sharing on hybrid AC-DC microgrid is demonstrated by using MATLAB/SIMULINK.**

Keywords—hybrid microgrid, droop control, power flow, AC fault, DC fault

I. Introduction

Recent technology development and practice in power system has witnessed increasing interests on the concept of “direct DC” [1]. In dc microgrid, the dc–dc bidirectional converters play an important role in the control of the internal dc bus voltage and in maintaining the system power balance [2]. The use of modern DC loads for their benefits in terms of efficiency, cost and system that can eliminate the dc-ac, ac-dc power conversion stages and their power losses [3].A microgrid is a discrete energy system consisting of distributed energy sources and loads capable of operating in parallel with or independently from the main power grid [4]. In AC or DC microgrids multiple reverse conversions requirement, increases cost and intricacy of the circuit and will reduce the efficiency of the system [5]. Microgrid operates in grid-connected and islanded mode where in grid connected mode, MG connected parallel to main grid to either draw or supply to grid [6]. In the islanded mode, hybrid microgrid control power flow between the AC and DC microgrid through an interlinking converter [7]. The frequency in AC microgrid and DC voltage in DC microgrid are maintained stable in the acceptable ranges by the interlinking converter. Hybrid AC/DC microgrid are an emerging power distribution scheme which can more efficiently integrate local renewable energy sources based distributed generations (DGs) and energy storage systems (ESSs), and to provide high reliable power supply for the local loads compared to a pure ac or dc MG [8].

In hybrid AC/DC microgrid system, BIC control can be applied using the droop control scheme for power sharing between AC and DC subgrids [9]. In [3], droop control with frequency and voltage deviation based balancing inputs have been performed, indeed merging them into one droop converter working together with other converters, in order to determine the corresponding reference power. Based on the droop control theory, all controlled converters participate in load sharing following the corresponding droop slope [10]. Renewable and small scale units need power electronic converters to be integrated with the existing power grid [11]. Modern power electronic switches can operate at high frequencies. The higher the operating frequency, the smaller and lighter the transformers, filter inductors, and capacitors [12]. The BIC should be able to control and manage power properly in both operating mode, grid-connected mode and stand-alone mode Operating the microgrid in stand-alone mode would lead to more challenges, particularly when the imbalance of generation and consumption happen because of flexible load and resources [13].

In AC/DC Hybrid microgrid system, one system is failure as disturbance, the protection scheme protect the another system. When the fault occurs at AC bus, DC bus power flow is maintained after isolation. The proposed coordination control strategy between the BIC and BESS converters can facilitate a smooth transition of the power transfer between AC and DC subgrids using the available resources and the last load. For overcurrent protection, the threshold setting of AC/DC link breaker and AC generator breaker are set 120 % of full load current.

II. AC/DC Hybrid microgrid configuration

This paper focuses on grid connected and standalone hybrid microgrid based on PV system, DG, BESS, AC loads and DC load. Fig 1 illustrates the proposed AC/DC hybrid microgrid model. The AC bus and DC bus are connected through 150 kW Bidirectional Interlink Converter (BIC). BIC is composed of bidirectional DC-DC converter and bidirectional DC-AC converter and also consists of isolation transformer. When the system faults or short circuit occur at one side, this transformer will isolate another bus to protect the system. Power management and frequency/voltage stabilization are performed by droop control strategies in BIC. The power source on the AC side of the microgrid is a 150kVA diesel generator whereas the AC load is composed of 100kW. Power sources on the DC side of microgrid are 100kW PV system through DC/DC boost converter, a battery energy storage system with a rating of 20 kW which is connected through DC/DC bidirectional buck/boost converter. 20kW DC load is connected to DC bus.

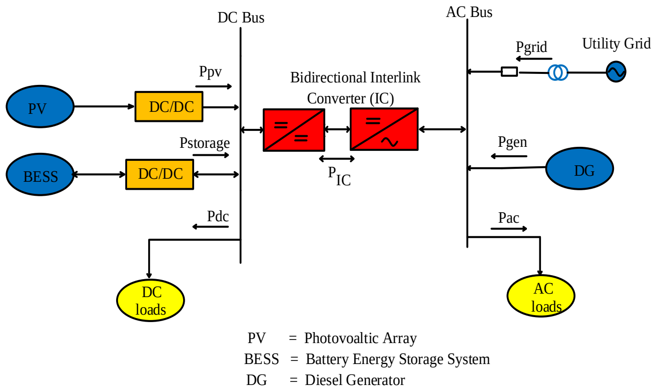


Fig 1. AC/DC hybrid microgrid configuration

III. CONTROL STRATEGIES IN AC/DC HYBRID MICROGRID

In microgrid, the system reliability and stability are achieved by the voltage regulation when more micro sources are interconnected. This voltage regulation damps the reactive power oscillations and voltage. In a complex power system, when multiple DGs are attached to the microgrid, the power sharing among them is done properly with the help of a control strategy called droop control. Droop control also enables the system to disconnect smoothly and reconnect routinely to the complex power system [14].

A. Droop control in BIC

In this study, the BIC connects the AC and DC grids and control the frequency of AC grid or DC voltage of DC grid. The control block diagram of the BIC is shown in Fig.2. The status of power in AC and DC grids is represented by the state of the hybrid microgrid that defines the control objectives such as frequency or DC voltage. The AC droop control and DC droop control equations are shown in equation (1) to (5).

$$\cdot \Delta f = \frac{f_{ref} - f_m}{f_{ref}} \quad (1)$$

$$\Delta V_{dc} = \frac{V_{dc,ref} - V_{dc,m}}{V_{dc,ref}} \quad (2)$$

$$\Delta P = (\Delta f - \Delta V_{dc}) \times \frac{1}{R_p} \quad (3)$$

$$P_{IC}^{*} = P_{IC,0} + \Delta P \quad (4)$$

$$\Delta Q = (V_{ac,ref} - V_{ac,m}) \times \frac{1}{R_q} \quad (5)$$

where,

$\Delta f =$ frequency deviation
$f_{ref} =$ reference frequency
$f_m =$ measured frequency
$\Delta V_{dc} =$ voltage deviation on DC Microgrid,
$V_{dc,ref} =$ reference DC voltage
$V_{dc,m} =$ measured DC Voltage
$\Delta P =$ active power reference
$P_{IC}^{*} =$ active power reference of IC
$\Delta Q =$ reactive power reference
$\frac{1}{R_p} =$ gain parameter of AC
$\frac{1}{R_q} =$ gain parameter of DC

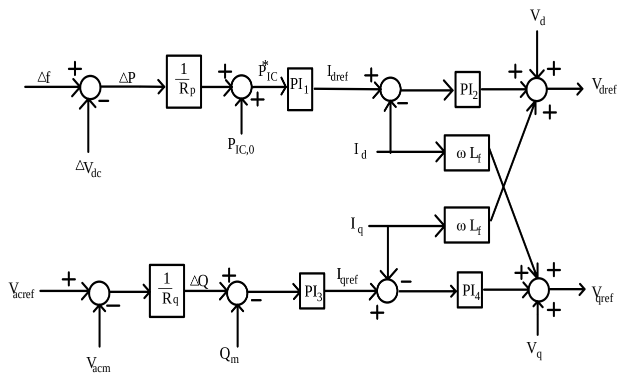


Fig 2. Control block diagram of the Bidirectional Interlinking Converter

The outer control loop which regulates V_{dc} and $V_{dc\text{-}ref}$ and the inner control loop which regulates I_d and I_q. Direct axis current component (I_d) is used to control the DC link voltage and quadrature axis current component (I_q) is used to regulate the reactive power. I_d current reference is determined from the output of the DC voltage external controller. I_q current reference is set to zero considering for zero reactive power. Voltage output converted from V_d and V_q in the current control loop are supplied to the Pulse Width Modulation (PWM) generator. PWM uses to supply the gate signals of AC-DC converter to obtain the stable output. It gives to reduce harmonics and to smooth the output. A phase locked loop (PLL) is device that causes one signal to track another signal. It is an important mechanism for synchronizing dc-to-ac converters with power grids [15]. PLL determines a signal to track another so that the output signal is synchronized with the input one both in frequency and phase.

B. Battery Charged/Discharged Controller

Fig 3. shows the block diagram of the charge/discharge controller. Generally, the switching losses of the IGBTs are high compared to the diodes; however, these can be reduced by eliminating unnecessary switching. Depending on the mode of operation, only one IGBT is needed to be switched at a predefined frequency. In order to select the proper IGBT, the reference current is compared to zero. If the reference current is negative, the controlled PWM signal is sent to S_1, activating the buck mode of operation. On the other hand, if the current reference is positive, the signal is sent to S_2 to transfer energy from the LV side to the HV side, activating the boost mode of operation [16].

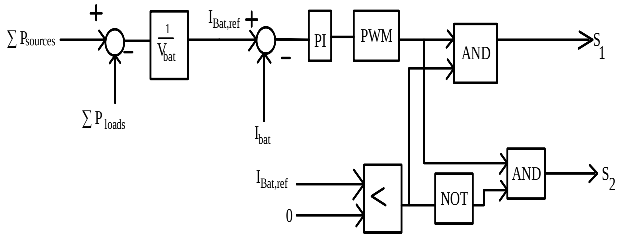


Fig 3. Block diagram of battery charged/discharged controller

IV. SIMULATION RESULTS AND CONDITIONS

A. Simulation Case

In order to confirm the control strategies of the AC/DC microgrid, computer simulations were carried out by using MATLAB/SIMULIMK. In this simulation, the converter switching losses is neglected. The main parameters of this system are shown in Table I and the simulation model is shown in Fig 5. In this paper, three cases of simulation were carried out considering for both grid-connected and standalone conditions. They are;

Case (I) : Irradiation changes

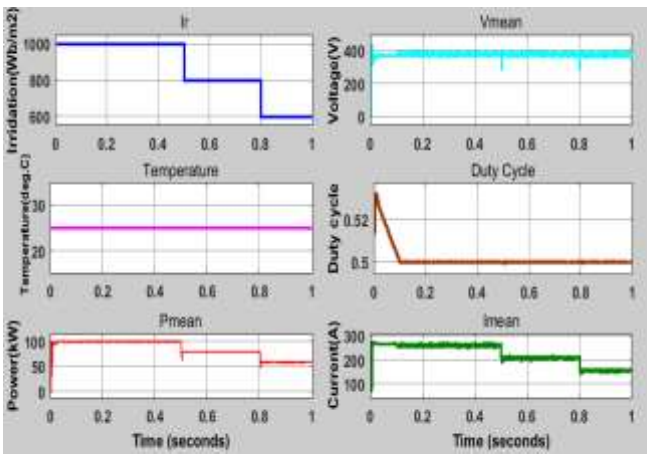
Case (II) : DC fault and

Case (III) : AC fault are considered.

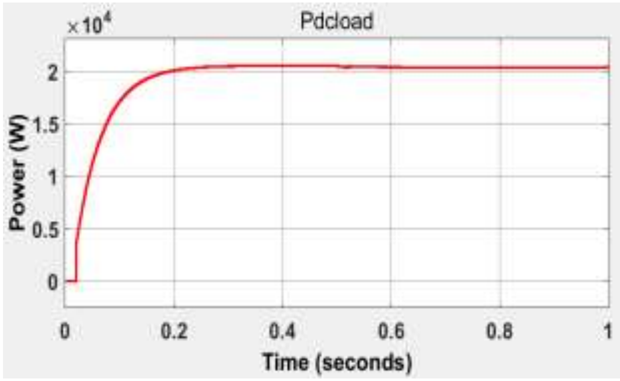
B. Simulation results

a) Case (I) : Irradiation changes

In this case, considering the stand alone mode, grid and generator are off at AC bus. PV system is operating with the irradiation changing (1000, 800, 600 W/m^2) shown in Fig 4(a). At 0-0.5s, PV system produces 100kW and 20kW from the energy storage (BESS) system shown in Fig 4(d). The power produced by PV is reducing depending on Irradiation change. However DC load is constant at 20kW and AC load is 80kW as shown in Fig 4(b) and (c). When the PV power is not sufficient for power demand, the BEES produces the required power for loads. The reference voltage is 780V and the mean voltage is the same as the reference voltage that is shown in Fig 4(e).



(a)



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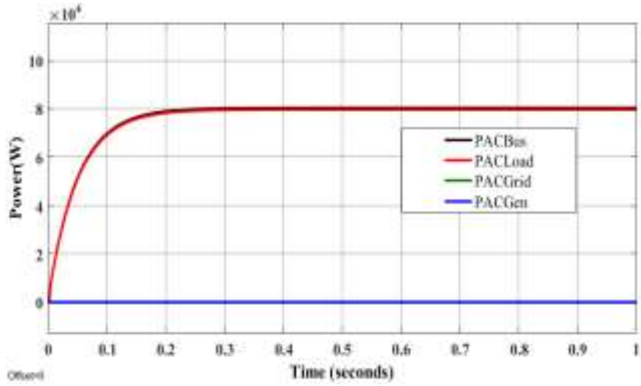

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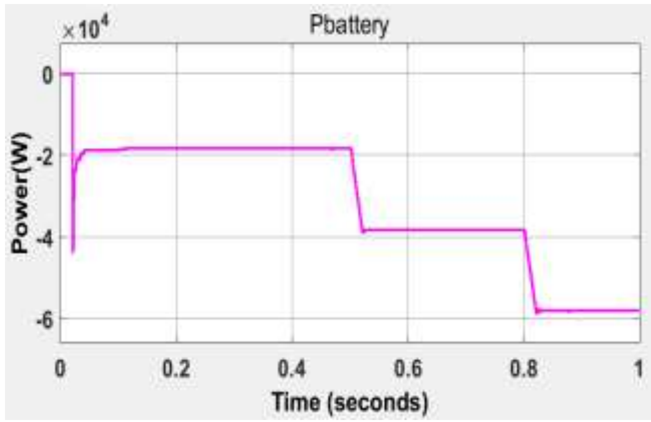

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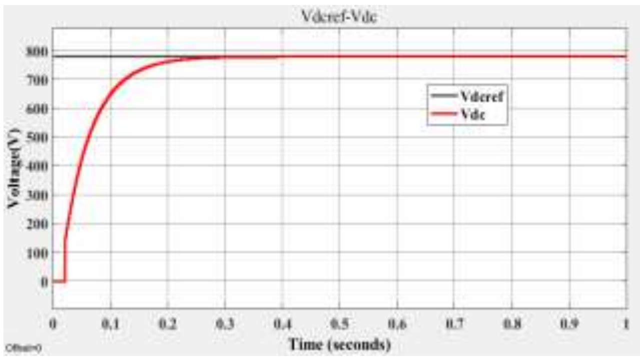


(e)

Fig 4. Irradiation changes condition; (a) PV capacity, (b) DC load (c) AC bus power , (d) Battery power and (e) DC bus voltage

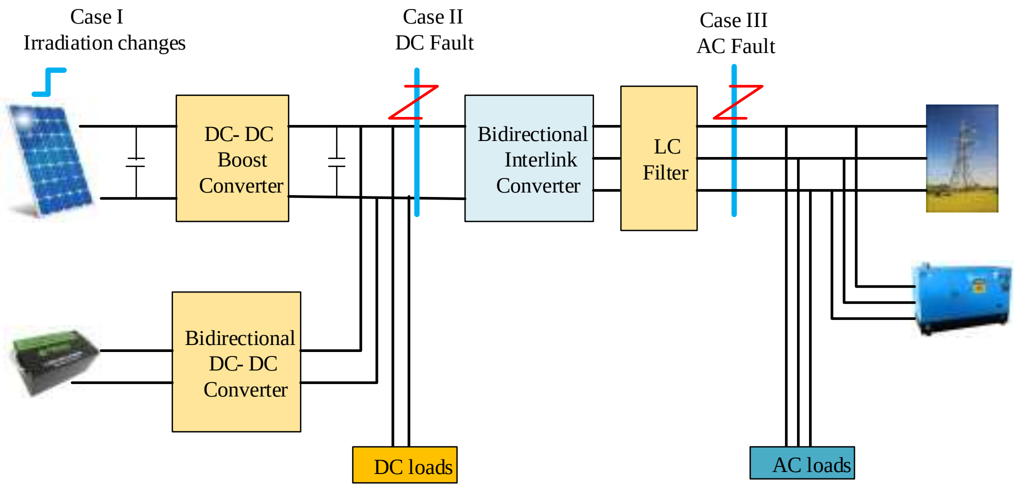


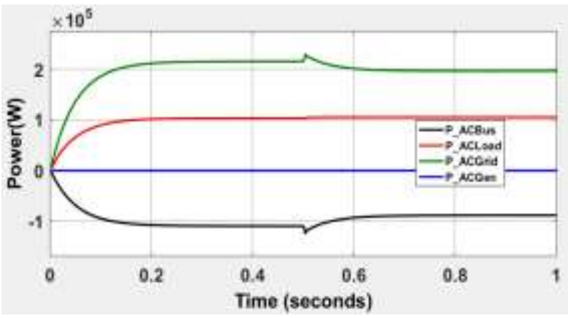
Fig 5. AC/DC hybrid microgrid mode

TABLE I. SYSTEM PARAMETERS

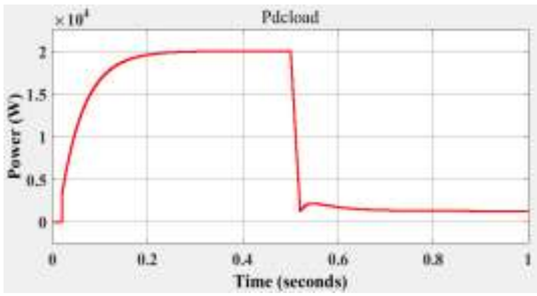
Sr. No	Type	Value
1	**PV** Rated Capacity String Voltage	100kW 380V
2	**Battery** Capacity of Battery Maximum depth of charge	200Ah ,780V 80 %
3	**Synchronous Generator** Output Capacity Output Voltage Internal Resistance	150kVA 400V 0.029876pu
4	**AC Grid** Rated Capacity Phase to Phase Voltage	1MVA 11kV
5	**Loads** AC load DC load	100kW 20kW

b) Case (II) : DC fault

In grid-connected condition, power flow is from AC bus to DC bus and battery is charged from 0-0.5s. When fault occur at DC bus, AC grid power was interrupted as shown in Fig 6(a). Fig 6 (b) and (c) show that DC load drops nearly to zero and battery produced high power due to DC fault at 0.5s. After isolation the DC fault bus by using DC breaker, the AC bus is maintained at 100kW of AC load which is shown in Fig 6 (d).



(a)



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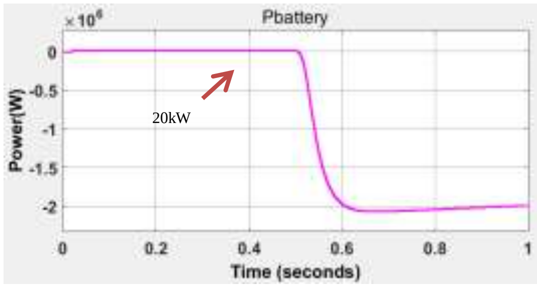

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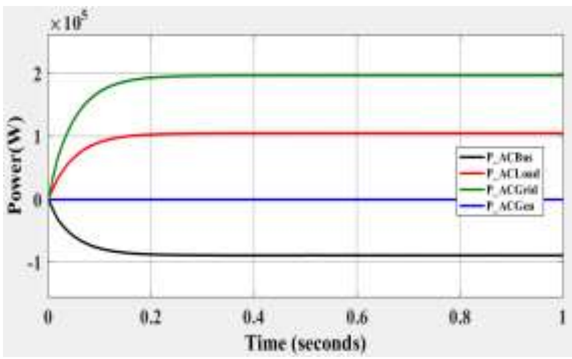
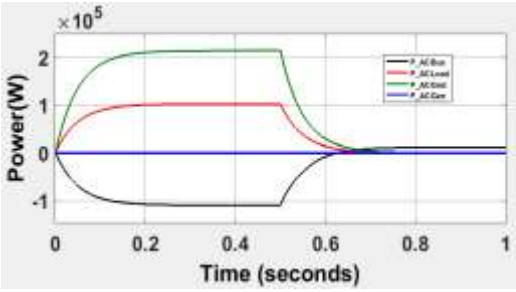


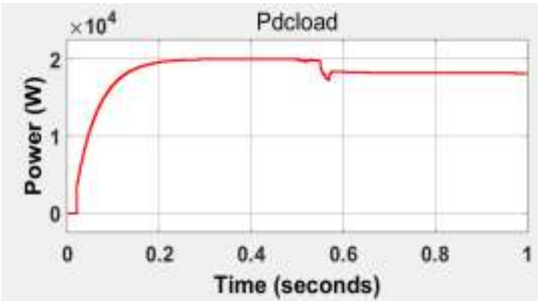
(d)

Fig 6. Fault at DC bus (a) AC bus power before isolation, (b) DC load, (c) Battery power and (d) AC bus power after isolation *c) Case (III) : AC fault*

When three phase fault occur in AC bus at 0.5s, AC grid off condition and the power flows from DC bus to AC bus although AC load have no power as shown in Fig 7 (a). Thus, DC load power is reduced to 18kW as shown in Fig 7 (b).In this condition, the battery power discharge to DC bus as shown in Fig 7 (c).When AC breaker is used to isolate the faulty bus, AC grid is also off condition. In this condition, there is no power flow from DC bus to AC bus and AC load as shown in Fig 8 (a). Thus, the battery can discharge 20kW to DC bus as shown in Fig 8(b). So, the DC load power is maintained 20kW after isolation to the AC fault bus. This condition is shown in Fig 8 (c).



(a)



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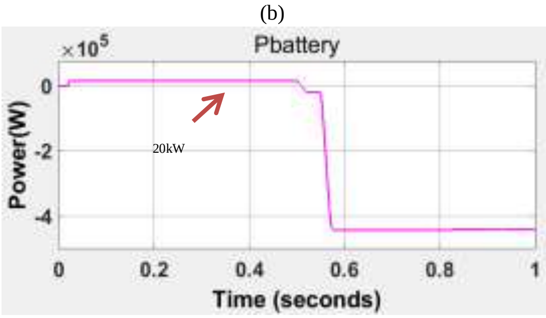
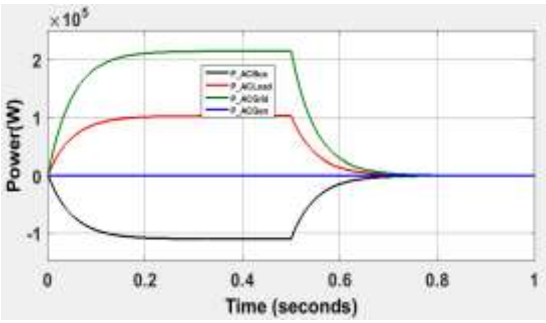
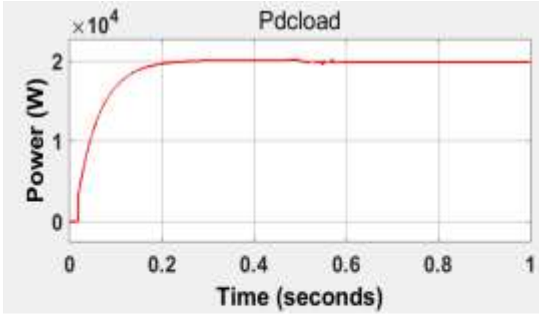


(c)

Fig 7. AC three phase fault ,without isolation (a) AC bus power, (b) DC load and (c) battery power



(a)



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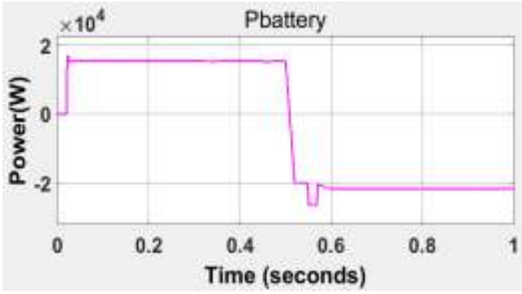

(c)

Fig 8. AC three phase fault, with isolation (a) AC bus power, (b) DC load and (c) battery power

V. Conclusion

In this paper, the bidirectional power flow of AC/DC hybrid microgrid under fault conditions is presented. The system consists of AC and DC subgrids connected by bidirectional interlink converter. In the system, droop control concept is applied for power sharing. AC circuit breaker and DC circuit breaker are used to isolate the system when AC fault and DC fault occur. To evaluate the performance of isolation circuit, AC fault and DC fault are applied at the simulation system. According to the simulation results, the system is isolated from the interrupted bus under both AC fault and DC fault conditions. Therefore, the protection scheme presented in this paper is reliable and protects for bidirectional interlink converter under fault conditions.

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